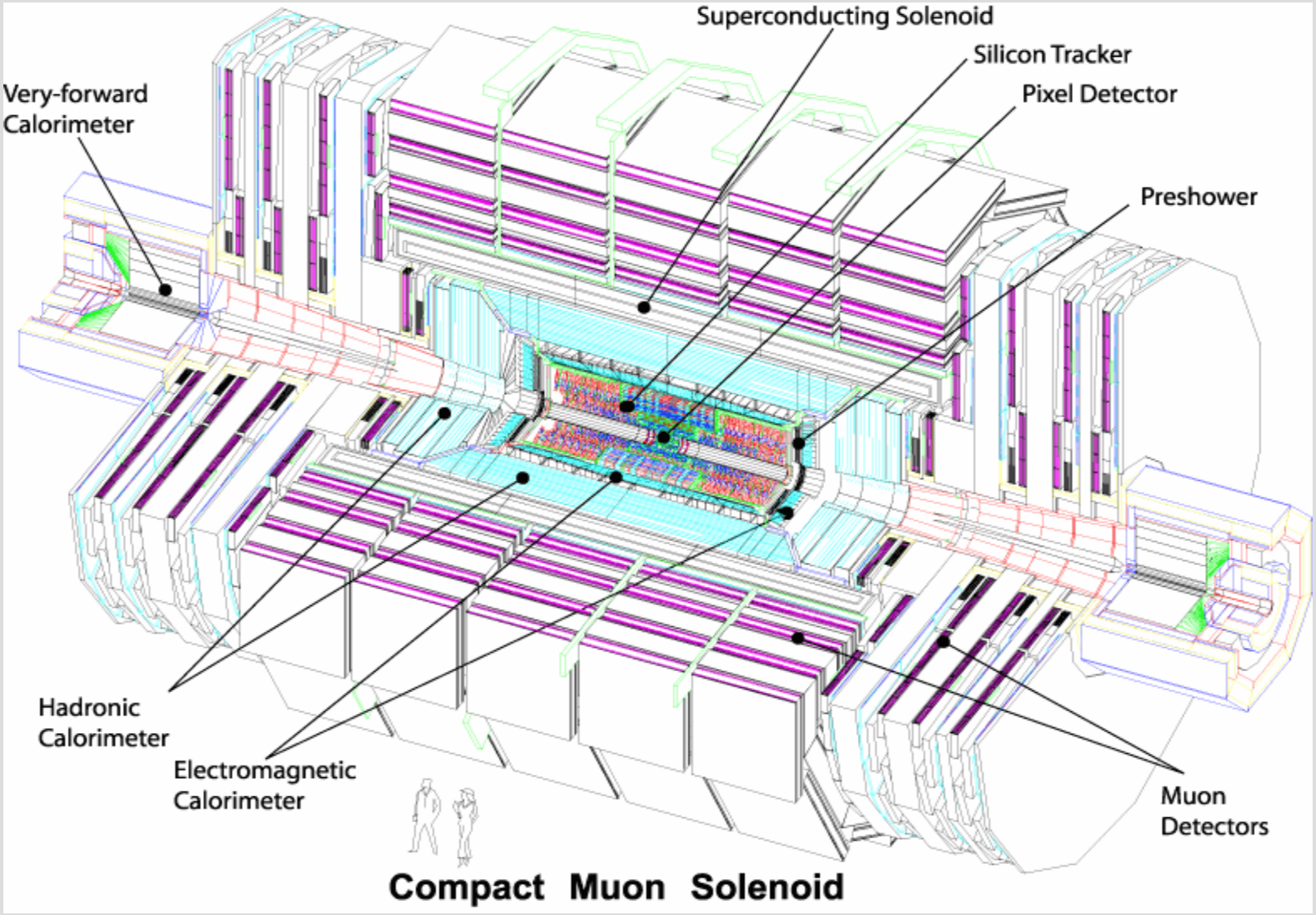
DOE Annual Program Review
Breakout Session – Collider Experiments
CMS: FNAL Construction

Simon Kwan

May 17, 2006

CMS Detector



CMS Construction Activities at FNAL

- EMU
  - Endcap Muon Chambers. Construction work completed and the project is now in a commissioning phase.
- HCAL
  - Construction of the Hadron Calorimeter completed. Commissioning at SX5 is almost done

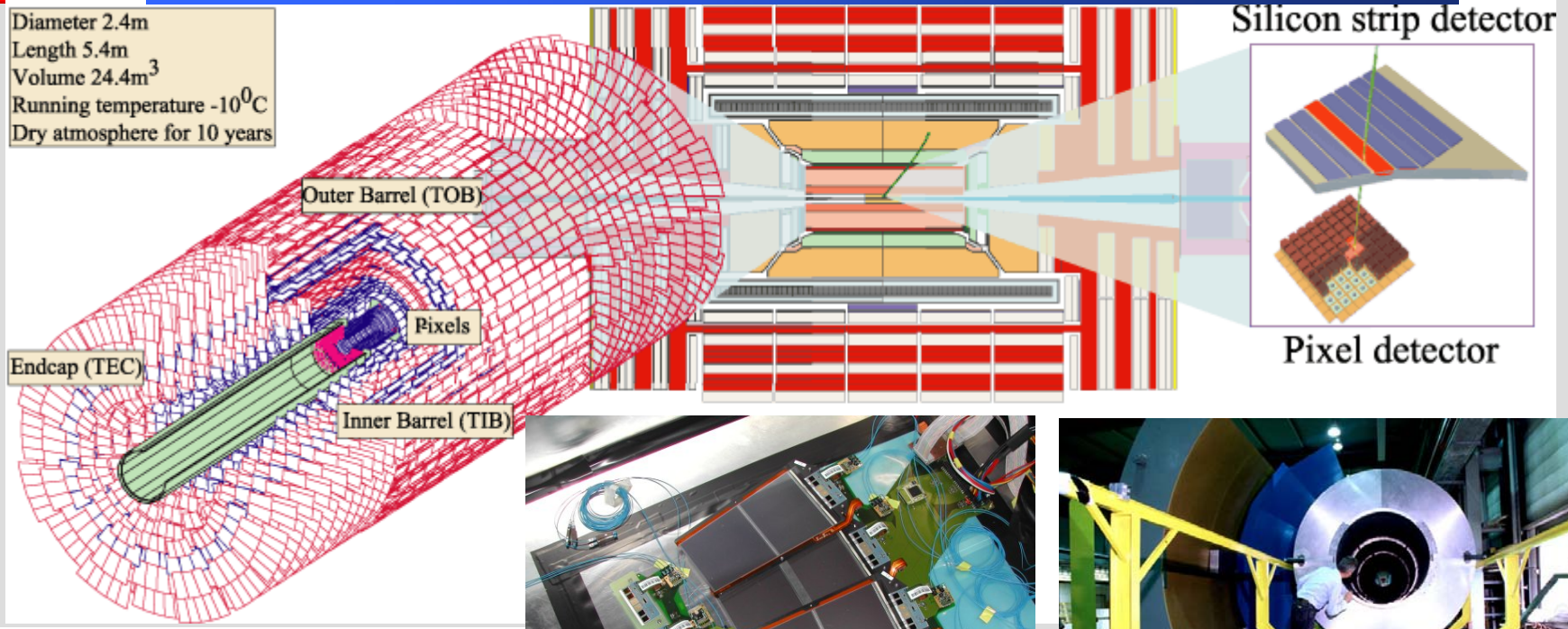
➢ Si Strip Tracker

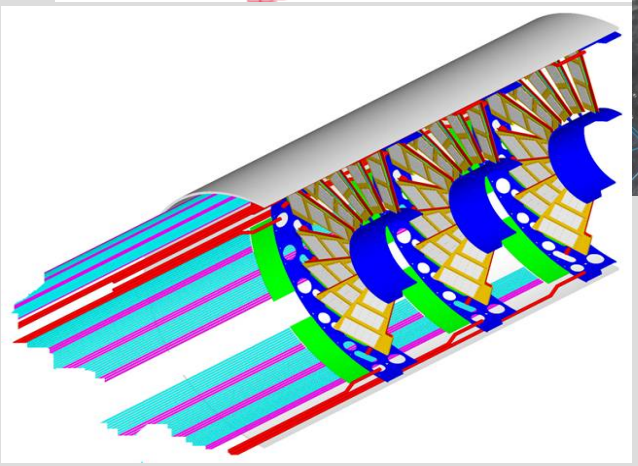
- **Assembly, testing, and delivery of all of the Tracker Outer Barrel silicon microstrip modules. Production of modules just completed. Rod assembly and testing will continue until June/July.**

➢ Forward Pixel Tracker (FPIX)

- **Project to build the Forward Pixel system. Ramping up production. Many production components are already in hand**

CMS Tracker



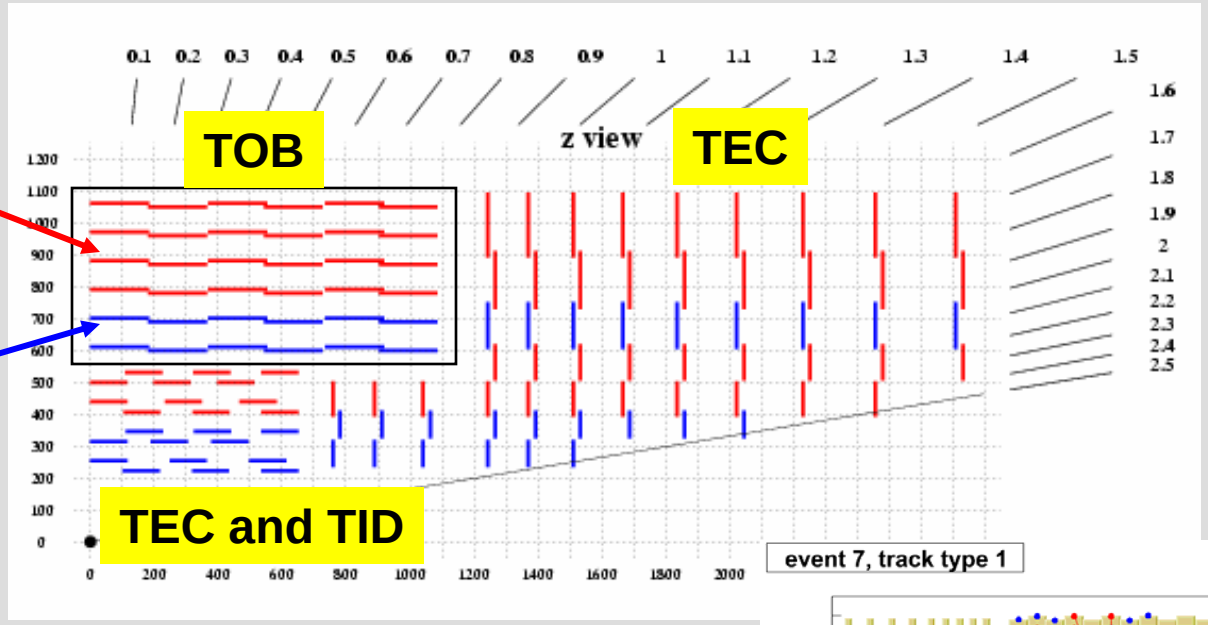


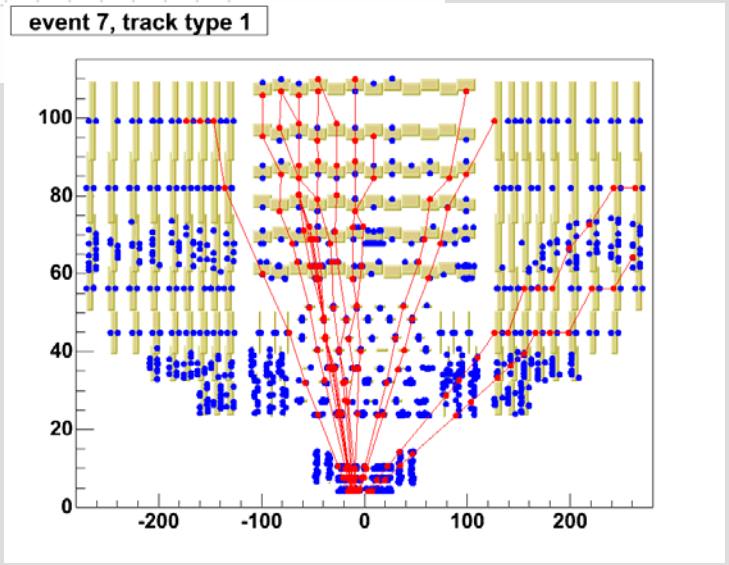
214m^2 of silicon sensors
11.4 million silicon strips
65.9 million pixels in final configuration

US Responsibilities
Strip Tracker and FPix

- Strip Tracker
  - Build all of the Tracker Outer Barrel (TOB) modules, test them, and ship them to CERN in the form of rods.
    - Production split 50/50 between FNAL and UCSB.
    - Components and test equipment provided by Tracker groups.
    - Strong participation by the US groups on Integration effort at CERN
  - Also build half of the R5,6, and 7 modules for tracker end cap (TEC)
  - **Modules production completed on April 26, 2006**
    - "25%" system test in late summer/early fall and installation in experiment starting in January 2007
- FPix
  - More extensive project to build all of the Forward Pixel disks. Includes component design, procurement, test, mechanics, and integration.
  - Production of components started in 2005.
    - Installed a small detector (4 blades) for pilot run in 2007
    - Full detector installed in 2008 after Pilot run
  - At FNAL, both the SiTracker and FPix activities take place primarily at the Silicon Detector Center (SiDet).

Tracker Geometry





Tracking relies on a limited number of precision points. There is a premium on keeping noise and inefficiencies as low as possible.

10,000,000 channels read by 80,000 APV chips

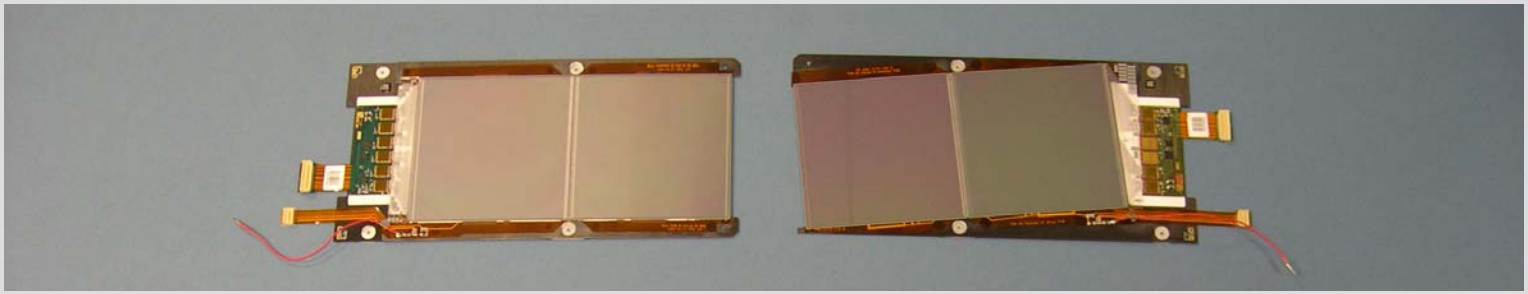
26,000,000 individual wirebond wires

200 m2 of silicon installed:100 kg of Silicon

Si-Strip Tracker Group

- **Brown University**
  - **R. Hooper, G. Landsberg, C. Nguyen, H. Nguyen**
- **University of California, Riverside (UCR)**
  - **G. Hanson, G.Y. Jeng, G. Pasztor**
- **University of California, Santa Barbara (UCSB)**
  - **A. Affolder, S. Burke, C. Campagnari, F. Garberson, J. Incandela, P. Kalavase, S. Kyre, J. Lamb, D. Stuart, D. White + technicians**
- **University of Illinois, Chicago (UIC)**
  - **E. Chabalina, C. Gerber, L. Nigra, T. Ten**
- **Fermilab (FNAL)**
  - **P. Bhat, M. Demarteau, H. Jensen, A. Ronzhin, J. Spalding, L. Spiegel, S. Tkaczyk**
- **University of Kansas (KU)**
  - **P. Baringer, A. Bean, L. Christofek, D. Coppage**
- **Mexican Consortium:**
  - **Cinvestav: H. Castilla, R. Perez, A. Sanchez**
  - **Puebla: E. Medel, H. Salazar**
  - **San Luis Potosi: A. Morelos**
- **University of Rochester (UR)**
  - **R. Demina, R. Eusebi, Y. Gotra, E. Halkiadakis, A. Hocker, S. Korjenevski, P. Tipton**

TOB Modules

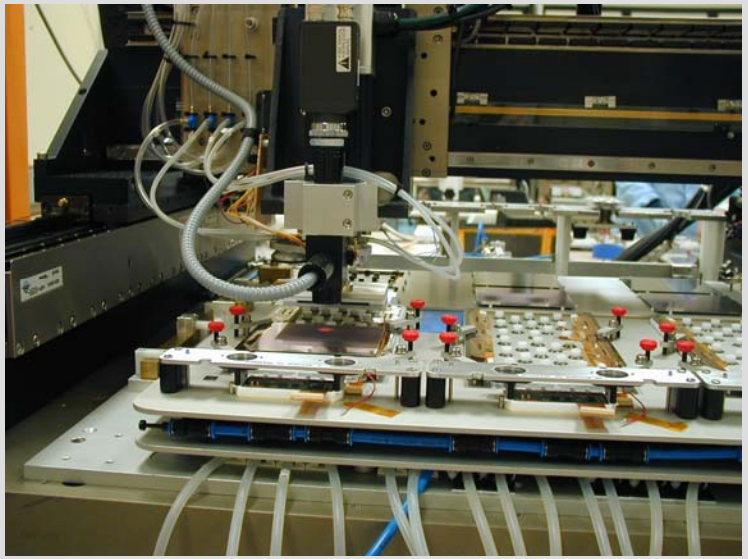


•Tracker Outer Barrel consists of 5,208 modules assembled in two ‘wheels’ each consisting of 6 layers of (688) rods.

- Sensors are approximately 10 cm x 10 cm.
- Modules always contain two sensors
  - Axial = RPhi
  - Stereo = 0.1 radian tilt angle
- Layers 1 and 2 are double-sided in the sense that they contain back-to-back axial and stereo modules
  - 12 modules per double-sided rod
  - 6 modules for all other rods (L3, L4, L5, and L6)
- TOB components (carbon fiber frame, sensor, hybrids, rod frames) were sent from different institutes to us

TOB Production Sequence

- Reception of components
- Bonding and testing of hybrids
- Robotic assembly of modules
- Optical inspection of modules
- Module wire bonding
- Reinforcement of modules
  - Silicone placed on backside of modules to prevent wire bond damage in shipping
- Fast testing of modules.
  - About 30 minutes per module.
- Long-term testing of modules
  - Up to 10 modules; thermal cycle in 12 hours
- Installation of modules on rod frames
  - 6 modules per rod (12 double sided)
- Fast testing of individual rods
  - Two hour test at room temperature
- Long-term testing of rods
  - Two day burn-in scenario
- Delivery of rods to CERN
  - Shipping crate holds 40 rods



US Module Assembly

4/24 - 4/28/06	Cumulative Modules Assembled								
	A	B	C	F gantry	PASS	% Pass	F ARCS	modules needed	Left to build or recover (using gantry F)
L12pu	508	28	10	0	546	100.0%	0	546	0
L12pd	522	17	5	3	544	99.5%	1	546	0
L12su	497	32	10	7	539	98.7%	0	546	0
L12sd	497	44	3	3	544	99.5%	1	546	0
L34p	1328	51	6	5	1385	99.6%	9	1380	-1
L56p	1655	47	10	6	1712	99.7%	8	1713	3
TOB total	5007	219	44	24	5270	99.5%	19	5277	3
								(not substracting ARCS F for TEC)	
R5N	349	15	1	0	365	100.0%	2	365	0
R5S	371	19	7	1	397	99.7%	1	398	0
R6	508	30	3	0	541	100.0%	1	541	0
R7	434	26	14	4	474	99.2%	2	503	25
TEC total	1662	90	25	5	1777	99.7%	6	1807	25
Total All	6669	309	69	29	7047	99.6%	25	7084	28

FNAL Si-Strip Tracker Testing

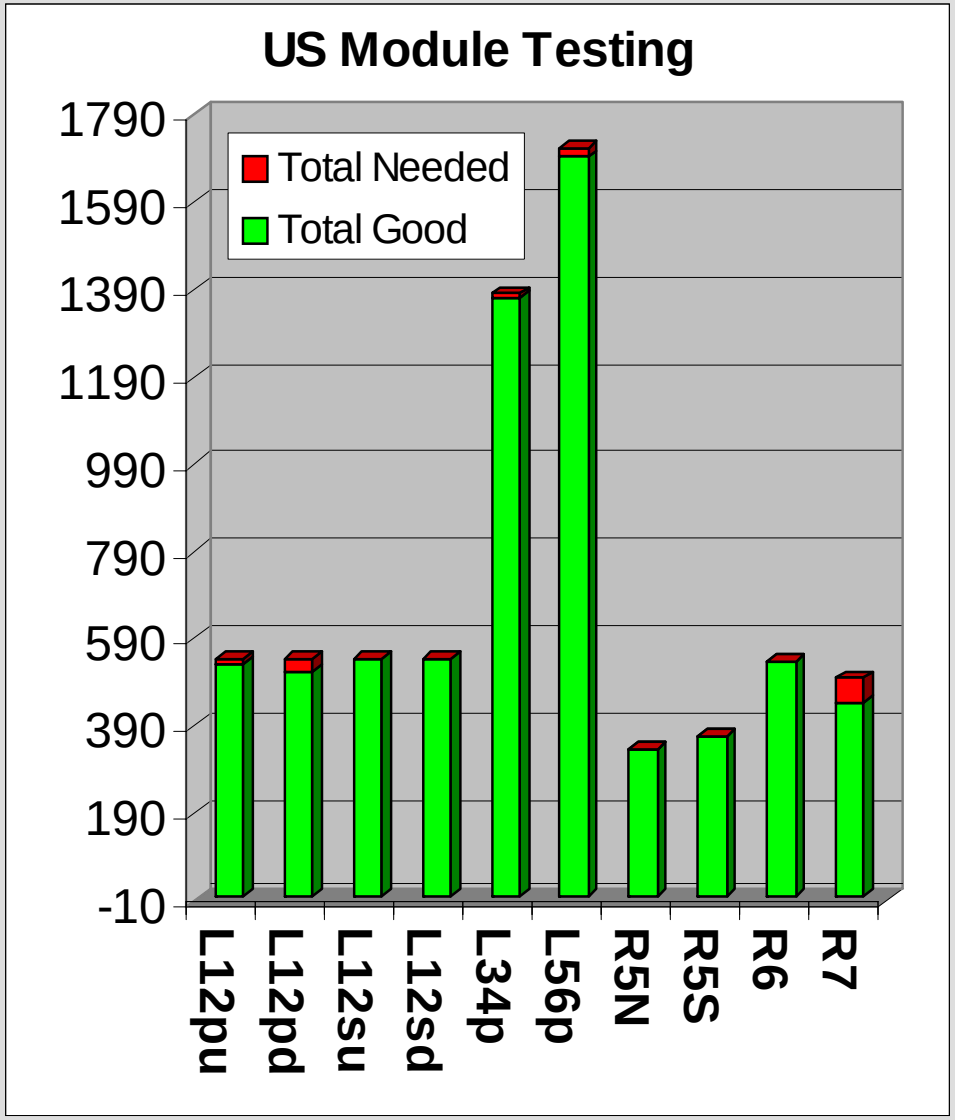
- Plot on right shows weekly and cumulative ARC test summaries as of a couple weeks ago.
- R7 are (TEC) modules
- Grade A designate fewer than 1% bad channels.
- In general the experience with the HPK sensors has been very good with fewer than 1 in a 1000 channels open or otherwise defective as determined by the ARC and LT tests.
  - Bonds are pulled for pinholes and shorts.

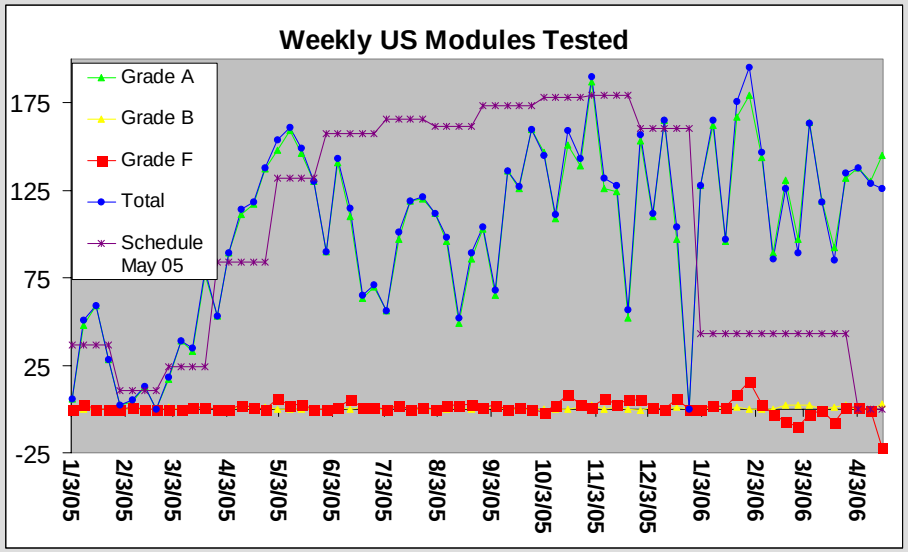
	Weekly			Cumulative				Still
	A	B	F	A	B	F	% A or B	Needed
L12pu	2	0	-2	285	1	0	100.00%	-3
L12pd	0	0	0	286	1	0	100.00%	-1
L12su	2	0	-2	287	4	0	100.00%	-7
L12sd	1	0	-1	279	3	0	100.00%	-4
L34p	1	0	-1	715	5	5	99.31%	1
L56p	2	0	-2	840	6	6	99.30%	-12
R5N	0	0	0	0	0	0	0.00%	0
R5S	0	0	0	0	0	0	0.00%	0
R6	0	0	0	0	0	0	0.00%	0
R7	0	0	0	228	1	3	98.71%	11
Total	8	0	-8	2920	21	14	99.53%	-15

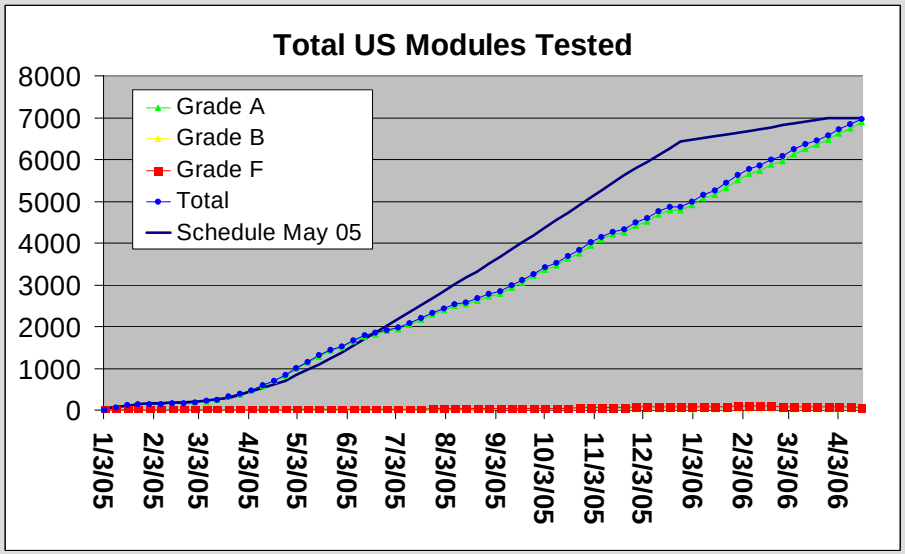
ARC = APV Readout Controller

FNAL ARC Testing Summary

US Module Testing Results

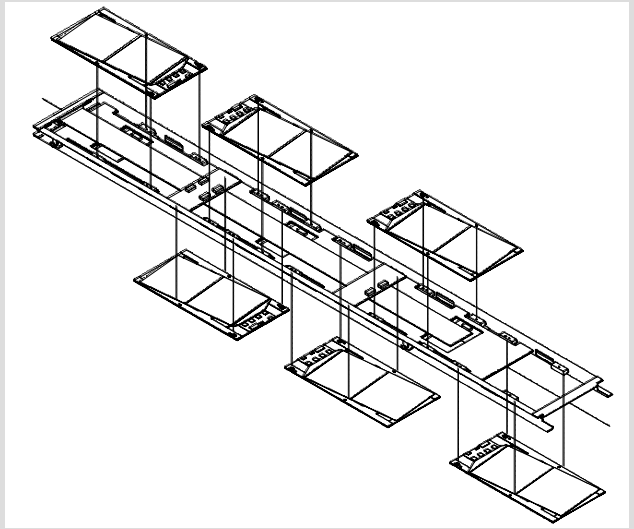




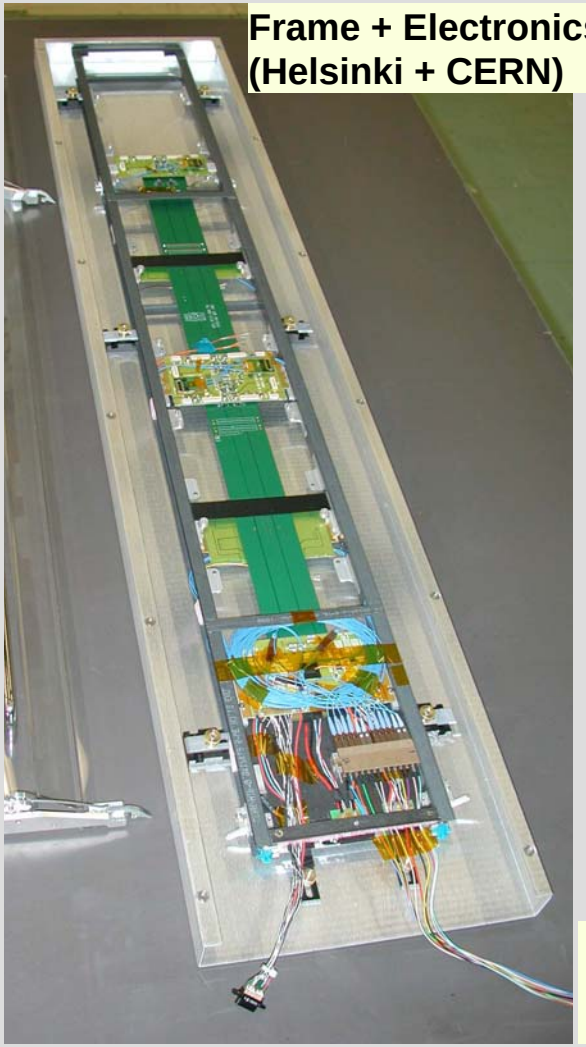


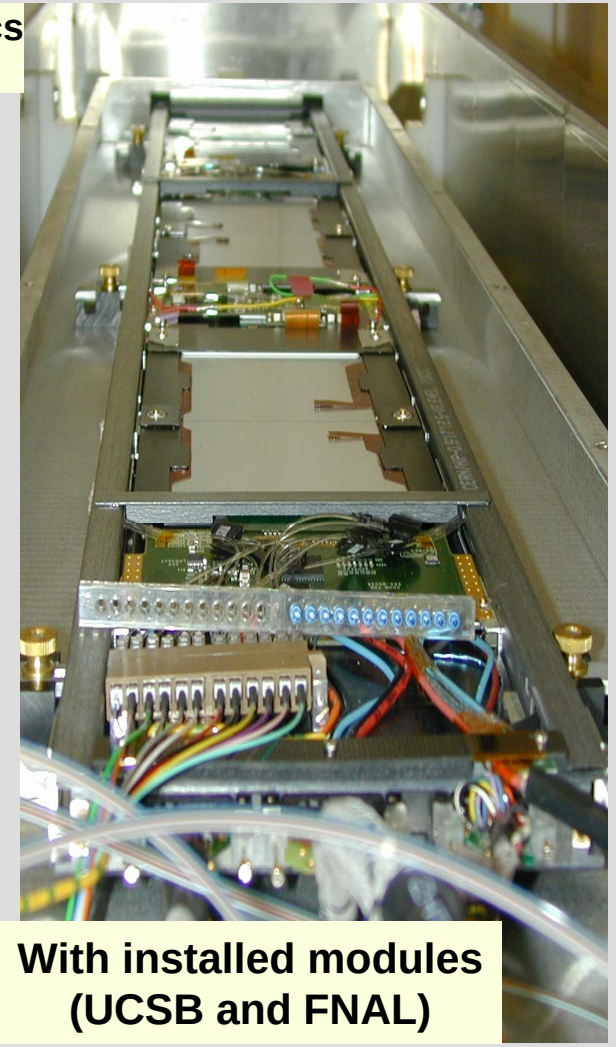
Rods

Carbon Fiber Frame (Helsinki)



Frame + Electronics (Helsinki + CERN)





With installed modules (UCSB and FNAL)

Modules mounted on support structures with integrated cooling & electronics

FNAL Rod Assembly and Test (cumulative)

Rod type	Total	Spare	Built	SRT Test	MRT Test	Shipped	Failed Rod Frames
SS4_H	52	5	9	9	7	5	
SS4_L	62		30	27	24	16	
SS6_H	72	3	66	59	58	50	2
SS6_L	68	3	55	48	48	32	1
DS_H_l1	23						
DS_H_l2	23	4	2	2	2	2	
DS_L_l1	24	2	6	6	6	4	1
DS_L-l2	20						
total	344	17	168	151	145	109	4

FPix Group

U of Colorado: M. Bunce, J. Cumalat, E. Erdos, V. Frusillo, K. Stenson, S. Wagner

Cornell U: J. Alexander, A. Ryd, K. Eckland, J.Thom, P. Wittich

UC Davis: J. Conway, R. Lander, D. Pellett, M. Searle, H. Powell, C. Veelken

FNAL: M. Atac, B. Baldin, J. Butler, G. Cardoso de Cardoso, G. Derylo, I. Fang, B. Freeman, P. Gartung C. Gingu, A. Hahn, S. Kwan, S. Los, M. Matulik, E. Ramberg, C. Selcuk, P. Tang, M. Turqueti, U. Joshi, L. Uplegger, W. Wester, J.C.Yun

U of Iowa: C. Newsom

JHU: B. Barnett, C.Y. Chien, K. Dongwook, M. Swartz, A. Peysner

Kansas S.: T. Bolton, Y. Maravin, D. Onoprienko, R. A. Sidwell, R. Taylor, E. von Toerne

Milano: P. D'Angelo, M.Di Nardo, S. Erba, S. Magni, S. Malvezzi, D. Menasce, L. Moroni, D. Pedrini, M. Rovere, S. Sala

Mississippi: L. Cremaldi, B. Quinn, D. Sanders

U of Nebraska: K. Bloom, D. Claes, A. Dominguez, M. Eads, S. Malik

NU: B. Gobbi, M. Kubantsev, E. Spencer, R.N.Tilden

Purdue U: A. Apresyan, K. Arndt, D. Bortoletto, G. Bolla, A. Garfinkel, D. Graves, M. Jones, P. Merkel, D. Miller, I. Shipsey, S. Son, B. Xin

Purdue U Calumet: N. Parashar, V. Cuplov

Rutgers U: S. Schnetzer, R. Stone, E. Bartz, J. Doroshenko, A. Macpherson, L. Perera, S. Sherman, Y. Streltsov

Vanderbilt U: W. Johns, P. Sheldon, E. Vaandering

U of Virginia: S. Conetti, B. Cox, R. Hirosky, M. Arenton, A. Ledovskoy, A. Kreymahdi, H. Powell, W. Stephens, D. Phillips, M. Ronquest, D. Smith, S. Zelitch

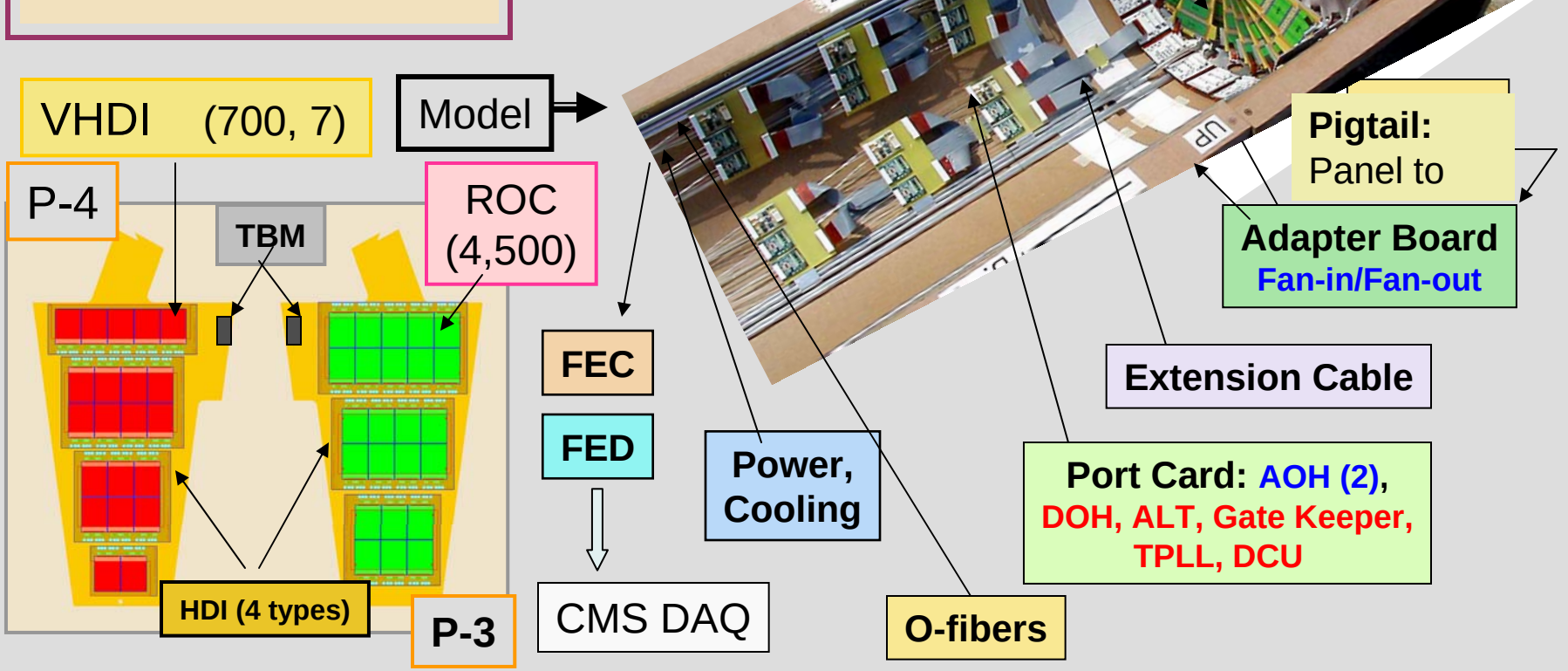
16 Institutions,
>100 Physicists

Overview of the CMS Pixel Disks

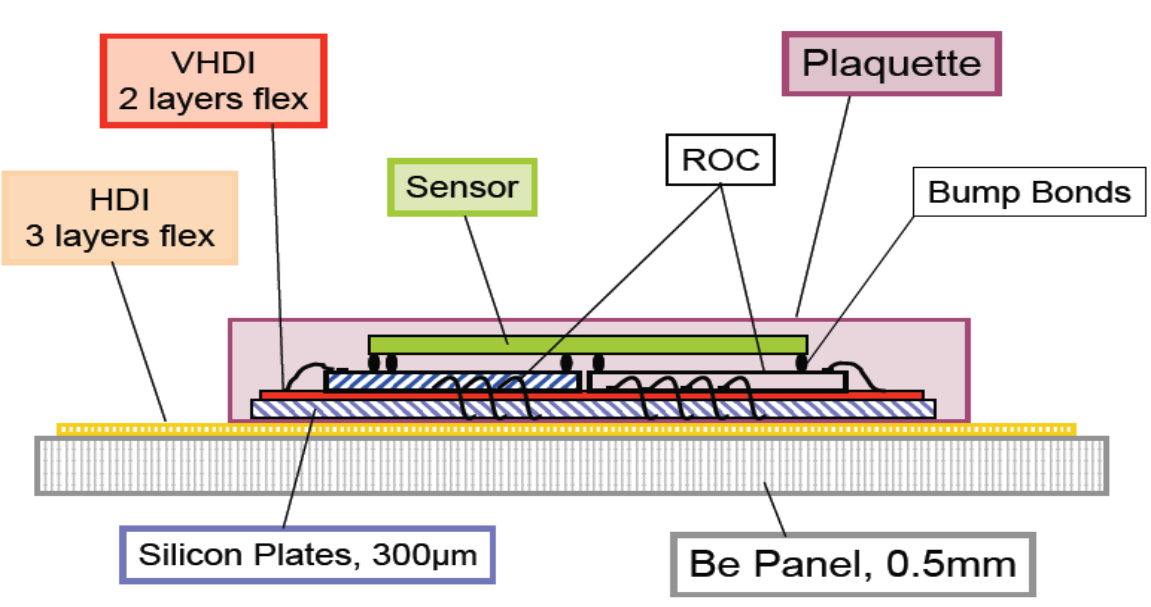
FPix (baseline):

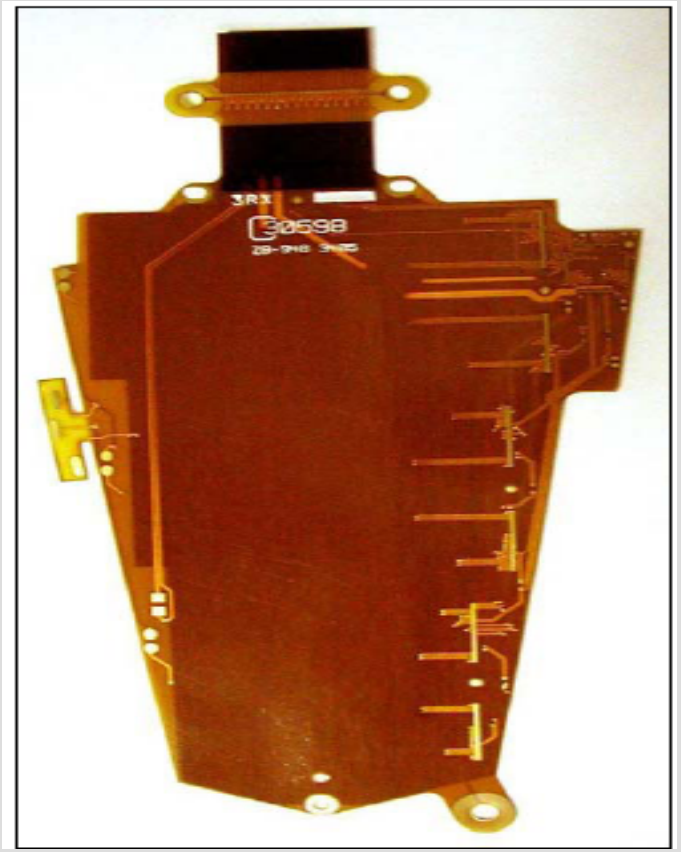
US delivers:

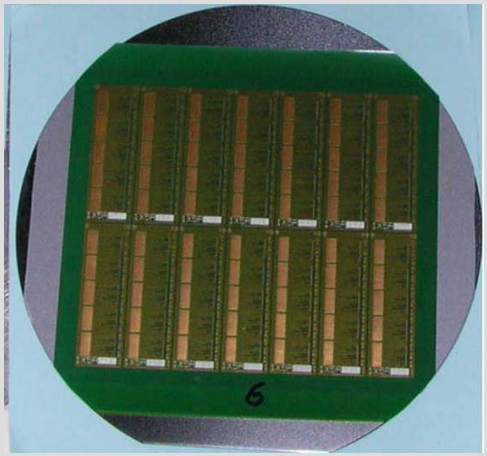
- **4 'disks'**
- **TBM** (for CMS Pixels)



FPix Terminology



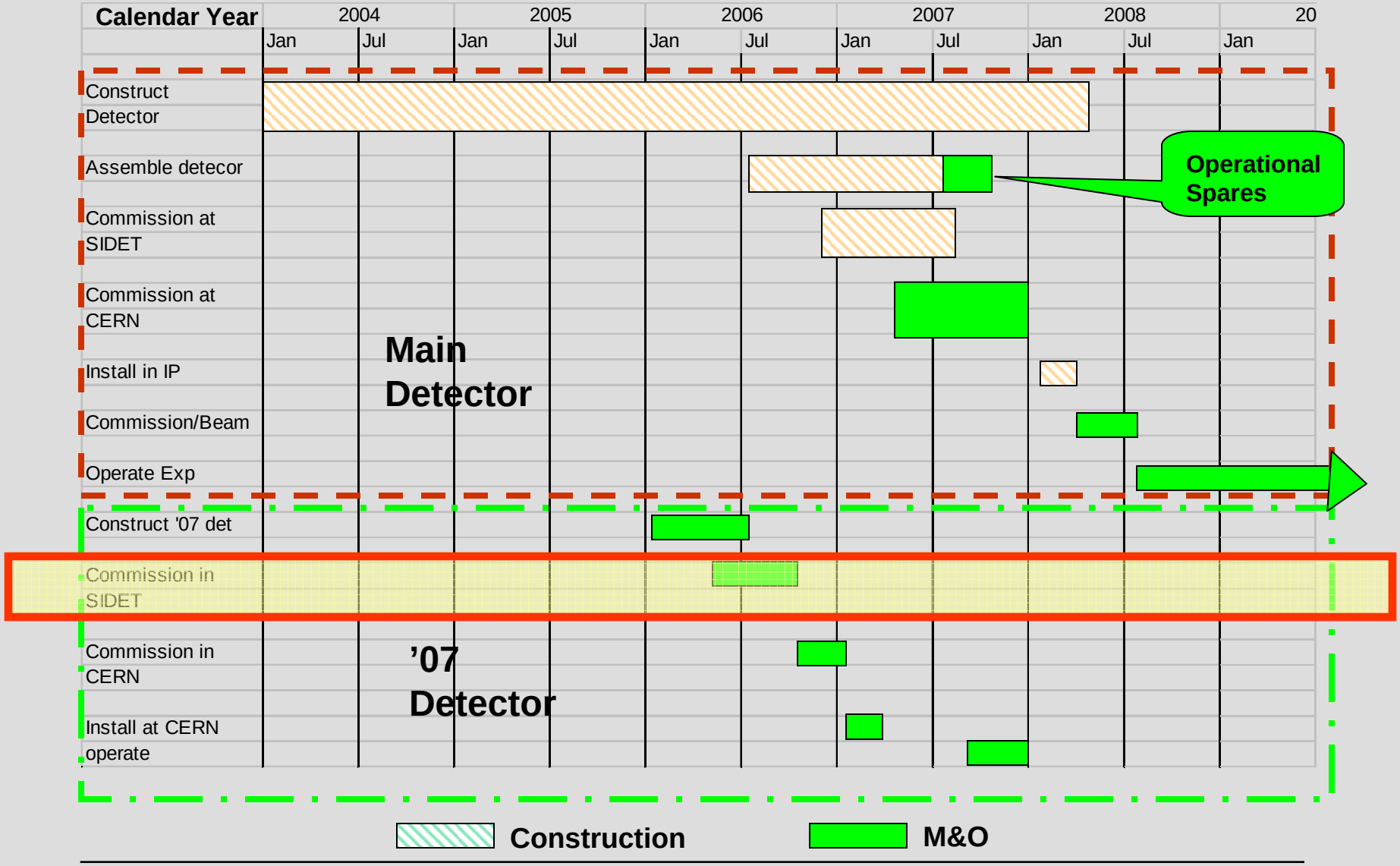




VHDI laminated on 300 µm Si

High density Interconnect before lamination to Be panel

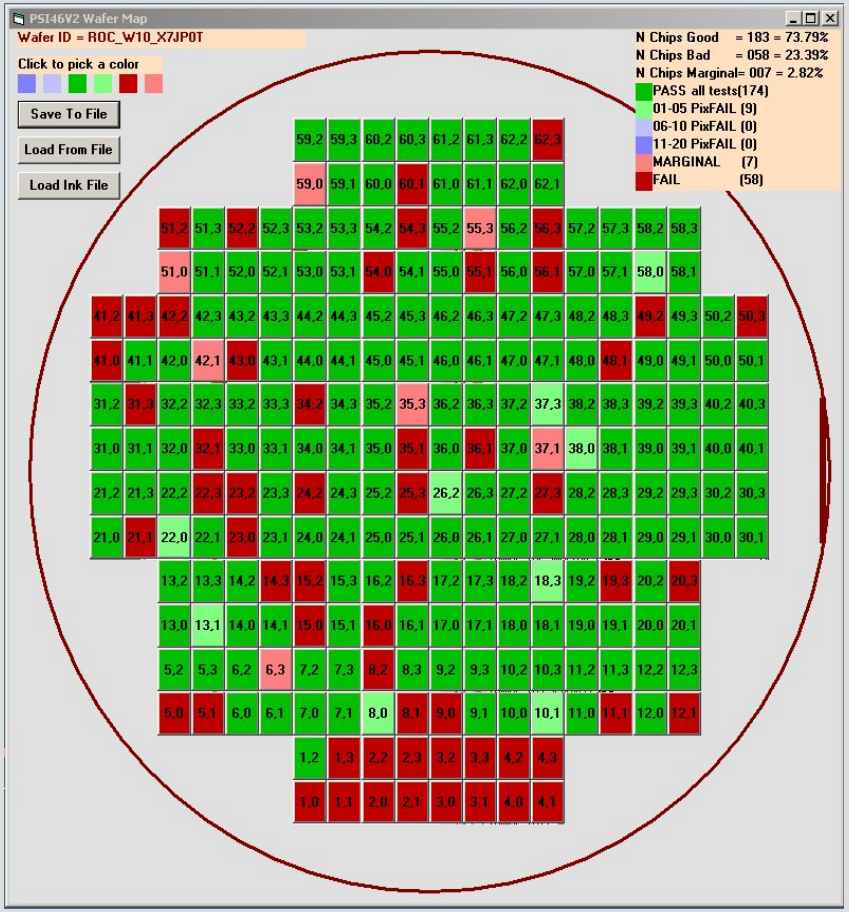
2007 Pilot Run and Fpix Schedule



FPix Status

- The order for the sensors has been completed. All sensor wafers have been received and tested (Purdue &JHU). Delivery of last batch ~ March 21, 2006
- The design of the ROC is the responsibility of PSI (Switzerland). We have now received all the production wafers that we will need (29 wafers)
- TBM (Rutgers) and other auxillary chips all produced and tested
- Production will be paced by the bump bonding process
  - Two companies have been engaged
    - IZM (Germany)
    - RTI (U.S.)
- Flex circuits –
  - VHDI : 7 versions; all parts in hand; lamination to Si, stuffing, and dicing done at Fermilab. Testing is done at KSU.
  - HDI : 4 versions; two versions in hand and being laminated to Be and then testing at SIDET; the other two have been sent out to vendors for quotes.
- Printed circuits:
  - Adapter boards: 4 types; 1st type produced and tested; Layout of the other three types now in progress
  - Port card: prototype has been tested and no problem found; production procurement soon
- Mechanical support:
  - Half service cylinder, support rings, cooling channels : prepare final drawings and start production soon

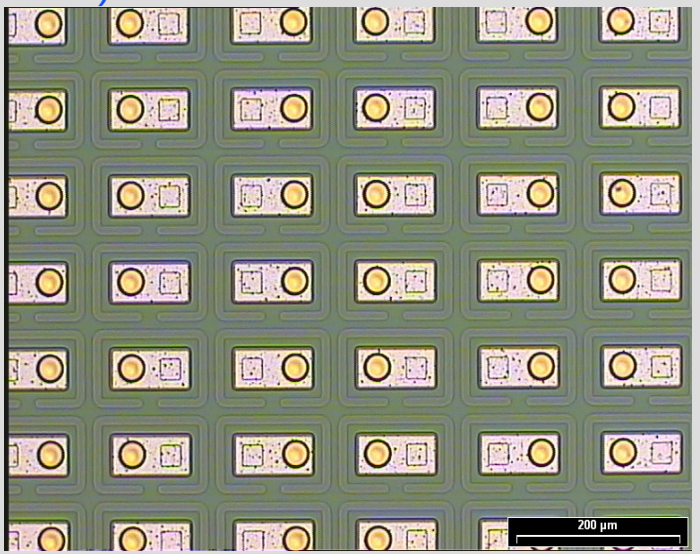
ROC Wafer Testing



- 8 wafers have been tested so far
- About 4 wafers per week
- Yield is consistent ~ 75%
- All results stored in construction DB
- Communication with PSI on test procedure and selection criteria
- Use two wafers to cross-check results
- Similar set up and circuit boards used to test TBM

Bump Bonding

- Received recently 46 preproduction bump-bonded modules from RTI. These will be used for the Pilot run in 2007.
- Decided to split production into two phases
  - Phase 1: 10% of full production order to each of two vendors
  - Based on yield and delivery schedule, will exercise the option of either awarding the rest of the contract to one or both vendor (split equally) (Phase 2)
- Phase 1 contracts established with IZM and RTI
- Each will get up to 4 ROC and 12 sensor wafers enough to build 12 good sets
- IZM
  - has already received and finished processing 12 good sensor wafers (sets) and started on the 4 ROC wafers
- RTI
  - Study yield and bump quality from preproduction run (46 modules)
  - Hope to send them the wafers within two weeks



- Expect to get modules back from IZM sometime around mid-June -> STARTING OF THE ASSEMBLY
- From that point on, we expect to get bi-weekly shipment from the vendors
- Expect delivery to be completed in 6 months ARO (Phase 2)

Flow Chart of Production Assembly @SiDet

All VHDI's in hand *

Plaquette Production

We are here

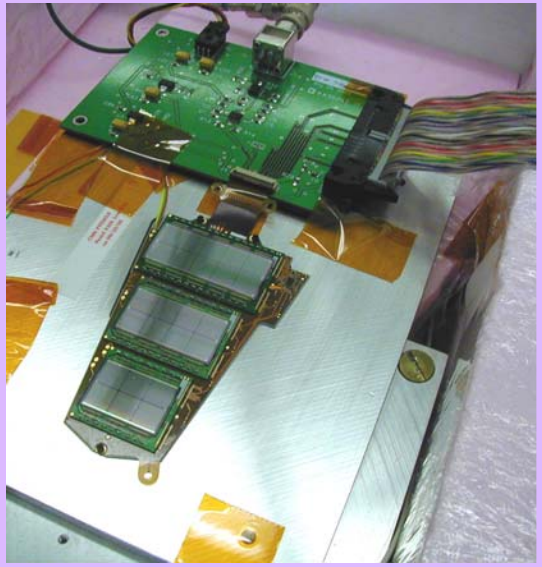
- VHDI Lamination on silicon wafer
- Populate VHDI with capacitors
- Dice VHDI sheet
- Probe testing of VHDI (@KSU)
- * Build Plaquette from Bump-Bonded Sensors/ROC, &VHDI) & Quick Test (Purdue)
- Burn-in of Plaquette
- Plaquette Qualification Test

All Be in hand *

Panel Production

We are here

- HDI Lamination onto Be
- Probe testing of HDI
- Populate with capacitors
- Install wires,TBM etc,
- Burn-in TBM& Panel
- Install PLAQUETTE on Panel
- Wire Bond Plaquettes to HDI
- Burn-in & Panel Test (NU, UNL, UVa, FNAL) ???



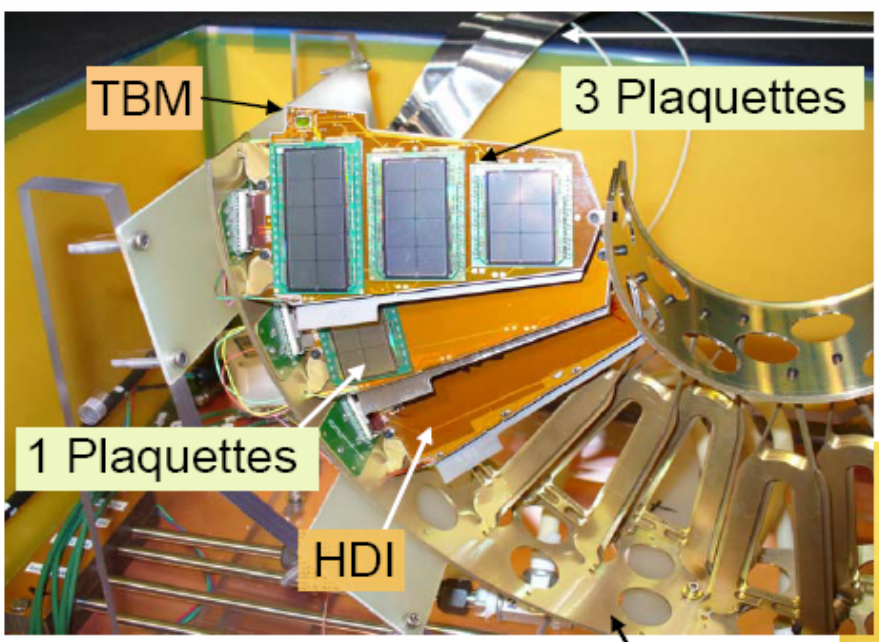
Final Detector Assembly

- Assemble Panels on Half-Disks
- Mount Half-Disks & Electronics on 1/2 Service Cylinder

Production Plaquette Testing Plan at SIDET

- Plaquettes arrive from Purdue after passing quick functionality test
- Immediately go to Burn-In Test ~3 days
  - Each Plaquette will have initial check-out to verify that we see correct analog output pulse train
  - After loading is finished, temperature will be cycled a number of times between room temp and -20^{o} C.
- All plaquettes which have passed the burn-in test will then undergo a Full Plaquette Characterization Test
  - Uses PTA Hardware Platform (FNAL CD) and software developed by Fermilab/Milano physicists
  - Cold Boxes and cooling systems by NU group
  - Final Plaquette "Grading Scheme" will be determined after we have accumulated statistics on ~100 plaquettes
    - About the number for the first full halfdisk
    - ~3 full weeks of production @ 6 Plaquettes/day (= Purdue production)
- Test Stand Status: 3 setups, undergoing final acceptance trials

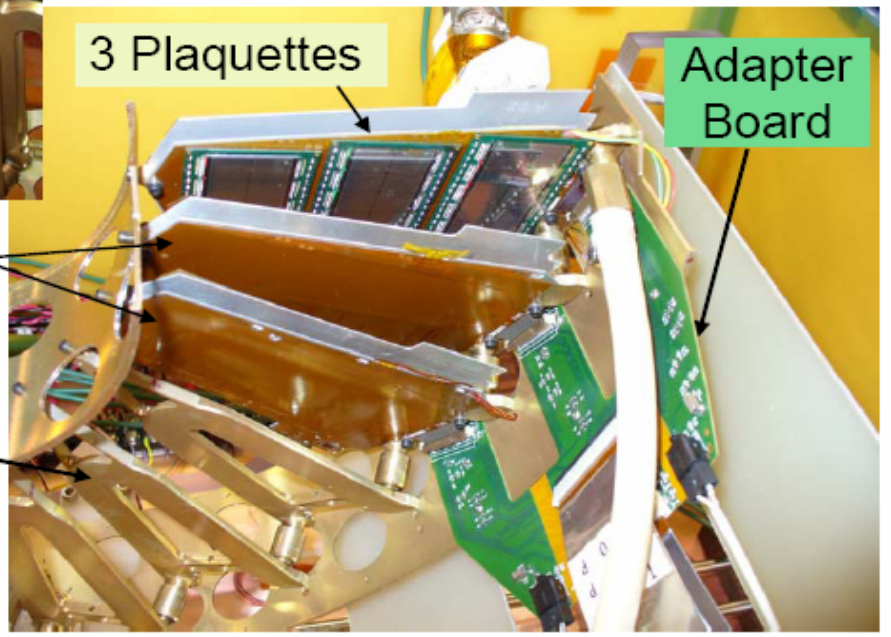
Prototype Half-Disk Test



Extension Cable

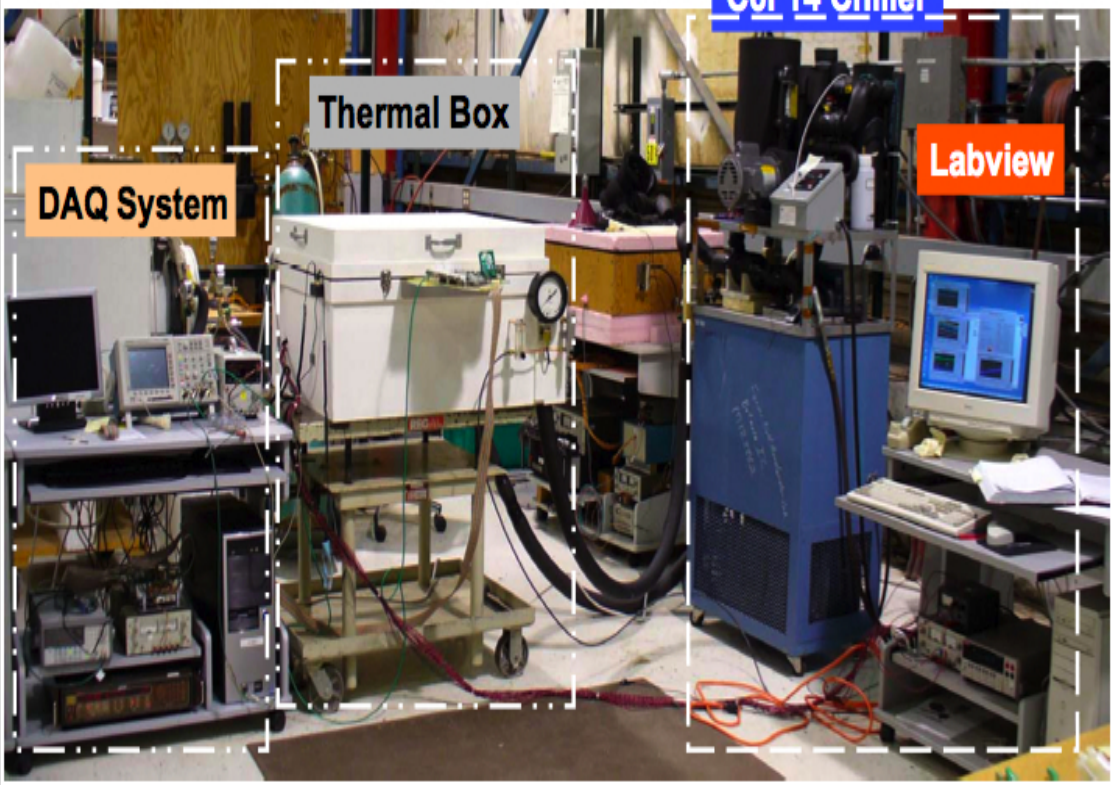
Side Facing IR

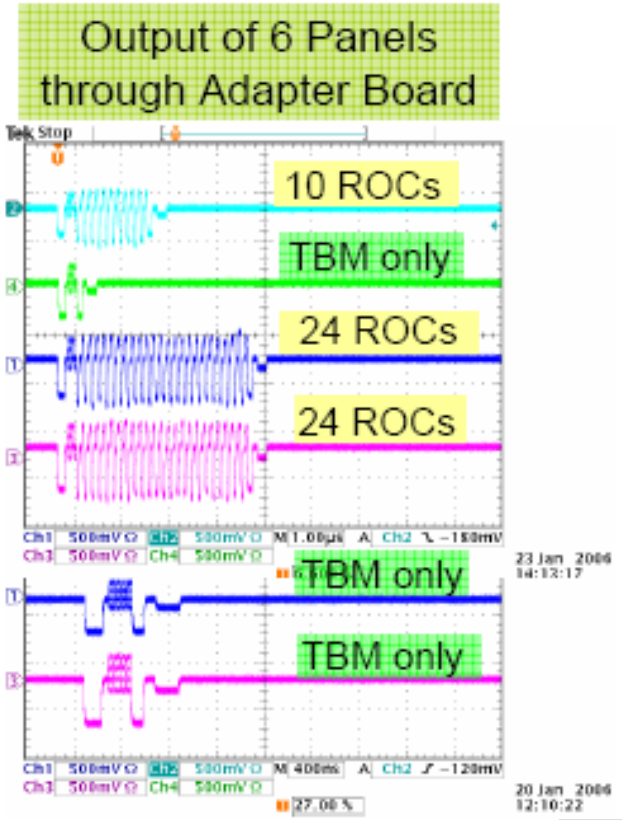
Side Facing Away From IR



½-Disk, Cooling Channels

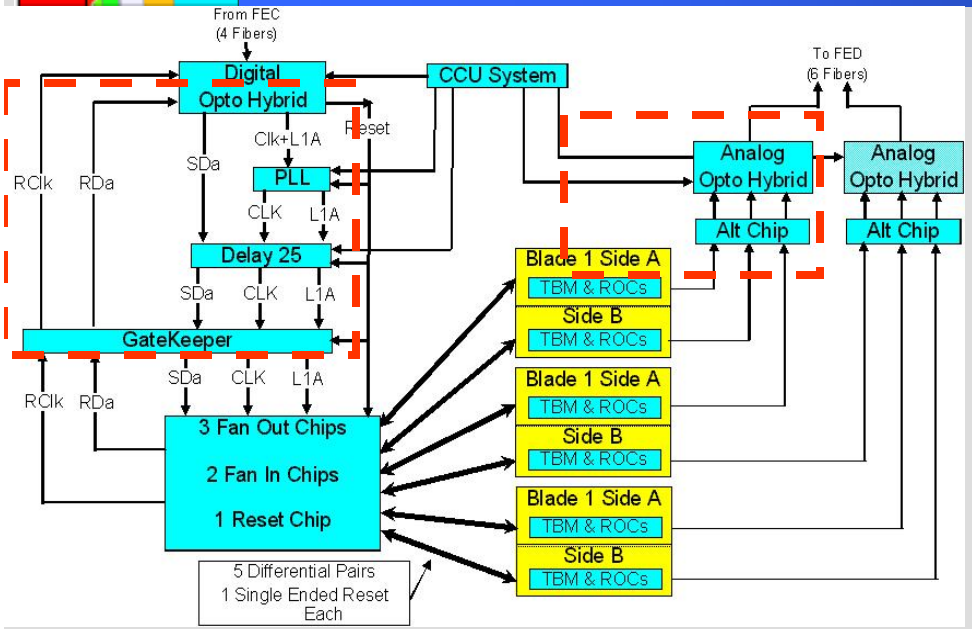
Half-Disk Test Setup and results



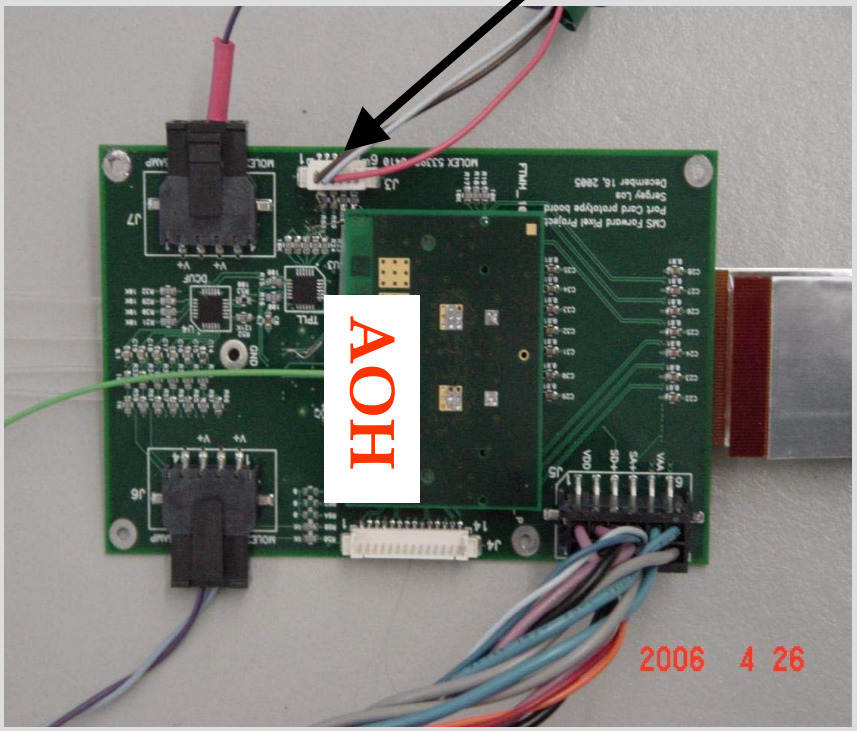


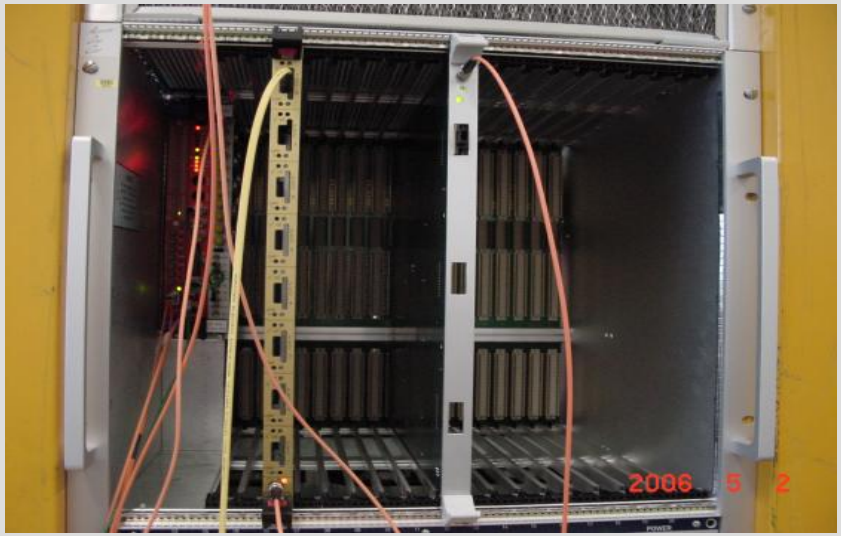
	Plaquette	Panel	Half-Disk
PreTests:	-Avg Vthr: 78 -Avg VCal: 141 -Avg CalDel: 80	-Avg Vthr: 78 -Avg VCal: 141 -Avg CalDel: 78	-Avg Vthr: ***87*** -Avg VCal: 137 -Avg CalDel: 82
Pix Alive:	-104 dead pixels (0.1%)	-156 dead pixels (0.2%) (***cluster of 52 new dead pixels on 2x4_ch4***)	-158 dead pixels (0.2%)
BB test D:	-2 bad bumps	-2 bad bumps (1 new, 1 old)	-7 bad bumps (***4 new on 2x4_ch4***)
SCurves:	-Avg Threshold: 79* -Avg Noise: 5.2*	-Avg Threshold: 82 -Avg Noise: 5.8	-Avg Threshold: 80 -Avg Noise: 5.4

Prototype Port Card

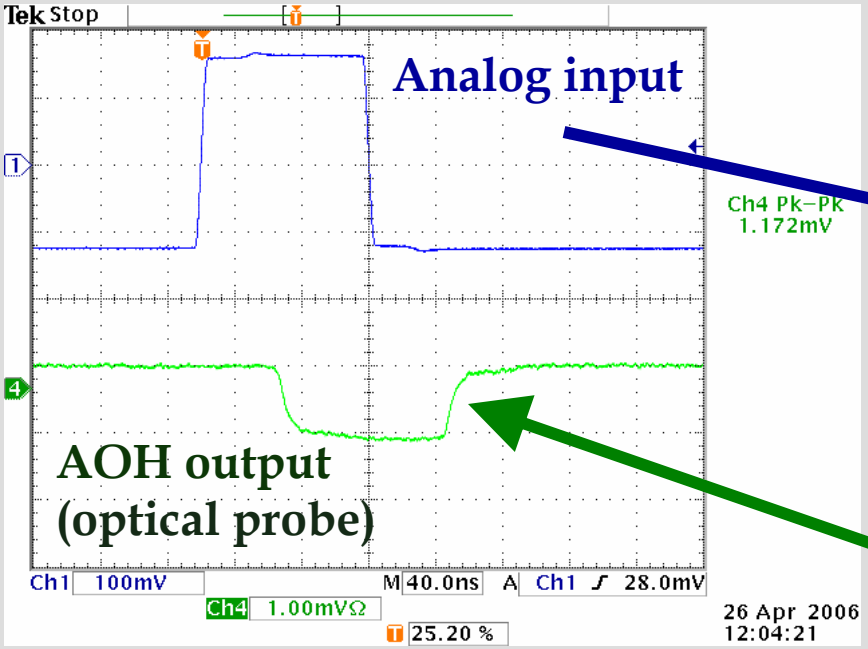


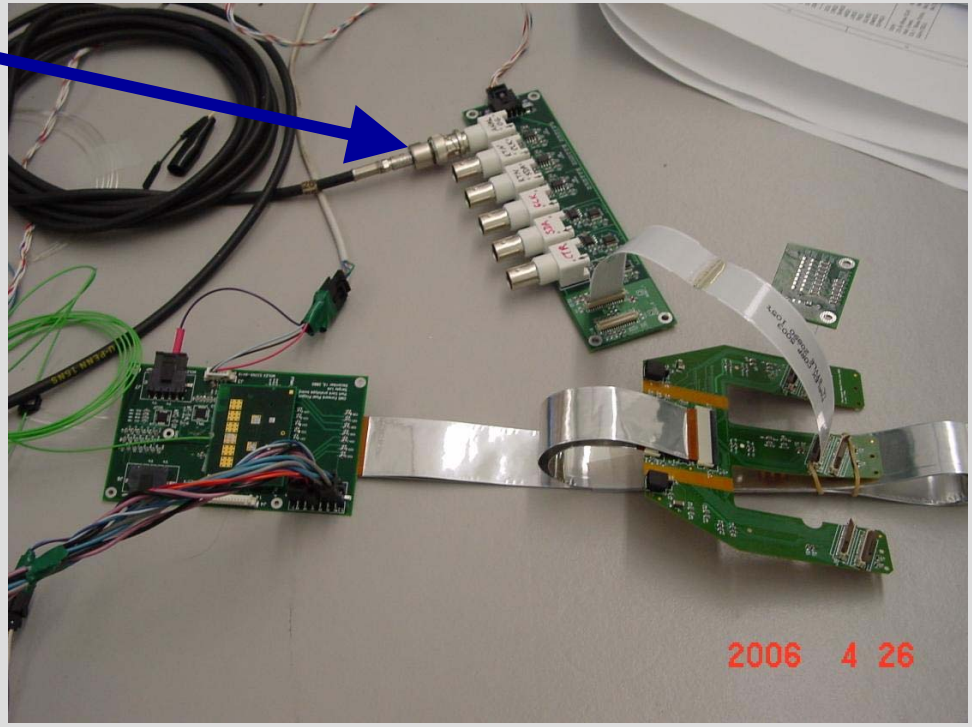
Slow I2C from CCU,
now commercial I2C controller





Analog Readout



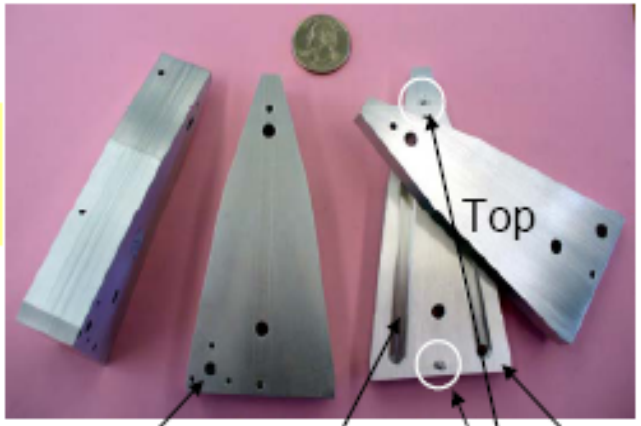


ROC → TBM → Extention cable → ALT → AOH → FED → data

Fabrication of Cooling Channel

Three step assembly :

1) Machine Blank Al Parts: Top and Bottom



Hole Nipple

2) Al Braze Parts

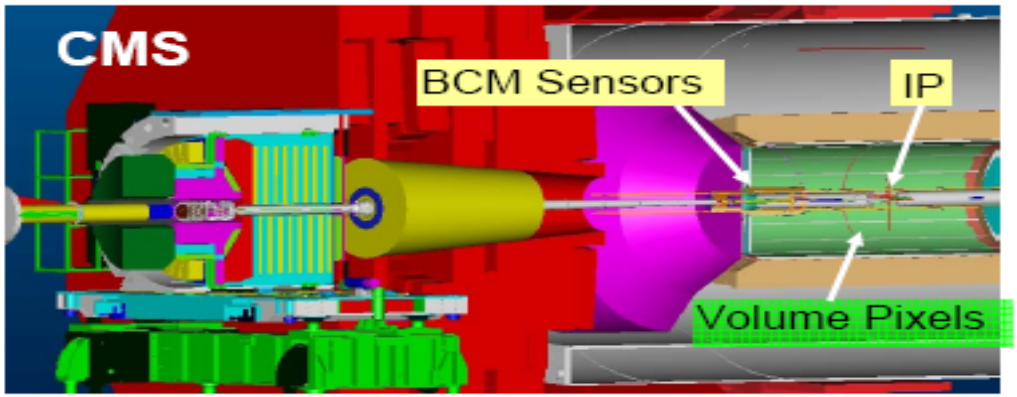
3) Machine Parts to Final Size

Fpix Service Cylinder

In the tight space from the IP to the TIB, there are five groups with detector/equipment: beam pipe, beam pipe support, barrel pixel, Fpix, and BCM.

BCM = Beam Condition Monitor

CMS management has requested that the Pixels be installed first in their final Position, and then the BCM be installed (and removed).



The installation of the BCM is not possible due to space constraints without modifying the end (at large z) of the Serv. Cyl.

A modified FPix Service Cylinder has been proposed.

An installation mock-up test will be performed at the end of this month at CERN